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ABSTRACT

This investigation of the possible effects of using calculators in mathematics teaching was based on an analysis of the cognitive and affective aims of mathematics education in the nine-year comprehensive school in Finland attended by all children aged seven through fifteen. The experiment consisted of a comparison of two fourth-grade classes using calculators with three control classes. Calculators were used in about 25 percent of the mathematics lessons of the experimental group during the study period. Results indicated posttest differences favoring the experimental treatment significant at the $p < .05$ level on understanding, application, and attitude tests. In addition, it was apparent that the lowest ability group seemed to profit considerably more than the others from the use of the calculator. (MP)

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Johannes Paasonen

THE ELECTRONIC HAND CALCULATOR IN FINNISH COMPREHENSIVE SCHOOL MATHEMATICS TEACHING

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The calculators were used in the experimental classes during approximately 25 % of the 75 mathematics lessons of the experimental period. They were used mostly for checking results and inductive introduction of new topics in connexion with a mathematics curriculum and textbook materials disregarding calculator use.

The results indicated posttest differences favouring the experimental treatment significant at the $p < .05$ level on the understanding, application, and attitude tests as well as a noticeable though non-significant aptitude-treatment interaction indicated by the fact that the lowest ability group seemed to profit considerably more than the others from the use of the calculator.

RESEARCH BULLETIN

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Helsinki 1980

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Helsinki, June 15th, 1980

Johannes Paasonen

1. INTRODUCTION

The rapid technological development in the industrialized countries has brought pressure to bear on schools to avail themselves of various technological innovations. These often entail considerable investments and, unless the need and possibilities of the new equipment are carefully weighed in advance, there exists a risk of costly didactical failure. Technological innovation must, then, proceed in accord with general and specific aims of education, and must be preceded by thorough theoretical analysis and empirical investigation.

The objective of this investigation is to evaluate the possibilities of using the electronic hand calculator as a didactical aid in mathematics teaching in the comprehensive school. Specifically it is meant to provide a basis for administrative decisions on the part of school administrators concerning the use of calculators. It is also meant to provide a basis for further research and more extensive experimentation on the use of the electronic hand calculator.

In chapter two some general features of mathematics teaching in the Finnish comprehensive school are presented together with the current official aims of mathematics education. A more explicit set of aims based on contemporary Finnish research is formulated to serve as a frame of reference for this investigation.

In chapter three, possible uses of the calculator at different levels of the comprehensive school are considered in some detail. The effects of using the calculator are discussed in respect to curricular structure on one hand and to the aims of mathematical education on the other hand. A brief summary of relevant research abroad is also presented.

In chapter four some relevant aspects of mathematical ability are defined and hypotheses concerning the effect of using the calculator are proposed.

Chapter five contains a description of an experiment involving use of the calculator in grade four, and a presentation of the results of the experiment. In chapter six the results of the investigation are briefly discussed.

2. MATHEMATICS EDUCATION IN THE FINNISH COMPREHENSIVE SCHOOL

2.1. Some Features of the Finnish Comprehensive School

The Finnish comprehensive school (peruskoulu) is compulsory for all children aged 7 - 15. The 9-year school is divided into an elementary school (grades 1 - 6) and a lower secondary school (grades 7 - 9). The teachers of the elementary school are principally class teachers, i.e. the same teacher teaches all or practically all subjects. The main exception is the foreign language beginning in grade 3 which is taught by a specialized teacher.

Grades 7 - 9 are taught by specialized teachers. In mathematics and foreign languages the pupils are grouped according to ability. In mathematics there are two ability groups in grade 7 and three in grades 8 and 9. The material taught in the different groups is chosen so that it should be possible for the student to switch to a lower or higher ability group during the autumn term of grade 7 and at the end of each grade. Choosing the lowest ability group in any of the streamed subjects - mathematics and languages - in grade 9 imposes severe restrictions on further educational possibilities.

The Finnish scholastic year consists of 190 school days. The number of weekly 45 minute mathematics lessons in the different grades is shown in table 2.1.

Grade	1	2	3	4	5	6	7	8	9
Math. lessons	3	4	3	3	4	4	3	3	4

Table 2.1. Mathematics lessons in different grades

2.2. The Mathematics Curriculum in the Finnish Comprehensive School

The mathematics curriculum for the Finnish comprehensive school was drawn up as part of the report of the Comprehensive School Curriculum Committee in 1970 (Mietintö 1970, I, II). It has been criticized for being too vague and superficial and giving rise to widely differing textbook materials. Selecting topics to be emphasized and others to be omitted has proved especially difficult for the non-specialized teachers of grades 1 - 6 who generally lack a thorough mathematical training. To remedy this state of affairs the National Board of Schools drew up a draft in 1976 for the Basic material in the mathematics curriculum. This work is based on the following principles:

1) Certain common aims are set for the whole age group so that the attainment of these aims gives a basis for further education.
2) The basic material is material which leads to the attainment of these aims and is taught to the whole age group.
3) In teaching, every effort is made to lead as large a part of the pupils as possible to a specified level in respect to the basic material. (Muistio 1976).

Although the basic material has not been officially authorized it has had a considerable effect on teaching practice especially due to the fact that the new textbooks have taken it into consideration. A revision of the basic material according to the experiences gained in using it is currently being undertaken.

While in the 1970 curriculum a considerable amount of new contents was introduced and several previously taught contents, notably systematic Euclidean geometry discarded, many new concepts and approaches, particu-

larly those relying heavily on the set concept, are not included in the basic material.

At the comprehensive school level a very obvious change compared to earlier practice was that almost all textbooks became of the workbook type, i.e. pupils were supposed to spend a considerable amount of time in individual work filling in blanks and working problems in spaces provided in the textbook. The newer textbooks of the lower secondary school are no longer of this type. Also at the elementary level there is a re-emphasis on the direct role of the teacher in structuring the learning process. Utilization of more varied methods of instruction than predominantly individual work is rapidly spreading.

2.3. The Aims of Mathematics Education

The specific aims of mathematics education in the comprehensive school have been formulated in the curriculum of 1970 (Mietintö 1970 II, 140) as follows:

> In mathematics teaching the aim is to promote the overall development of students particularly in the following respects:
>
> 1) Pupils are guided towards acquiring knowledge and skills chosen in accordance with the demands of the changing society and the development of the individual.
> 2) Pupils are guided towards acquiring work habits and techniques necessary for the independent search and utilization of mathematical information.
> 3) The attitudes of pupils towards mathematics are developed in such a manner that unfounded over- and underevaluation of the role of mathematics is prevented.
> 4) Pupils are given satisfying experiences while engaged in mathematical activity.

These aims are evidently quite acceptable but they can be criticized for not characterizing mathematics education in particular nor providing a concrete basis for decisions in teaching practice.

In this investigation the effects of the use of the electronic hand calculator are considered in respect to the aims of mathematics education. It was felt that the aims mentioned above should be made more explicit, in particular the first aim which is supposed to characterize the cognitive component of mathematics education. In spite of the fact that several categories have been proposed in the literature (e.g. Johnson and Rising 1967, Roller 1977, Sekretariatet for Nordisk Kulturelt Samarbeid 1972) it was felt that recent Finnish research by J. Leino could furnish a somewhat novel approach to the formulation of the aims.

In the investigation by J. Leino (1975a,b), teachers with the competence to instruct in higher secondary school (grades 10 - 12) were asked to judge the relative importance of a number of objectives for mathematics education. Factor analysis of the results yielded the following five factors for the cognitive domain:

A. Computation and use of basic concepts
B. Understanding mathematics
C. Application
D. Deduction
E. Language and form

In addition the factor analysis yielded two factors of the affective domain:

F. Participation and enthusiasm
G. Attitudes and work habits.

Following the five cognitive categories issuing from Leino's research we decompose the first aim of the curriculum of 1970 into the following five more explicit objectives:

> The cognitive aim of mathematics education in the comprehensive school is that the pupil
> 1) learns to perform mechanical computations and use basic mathematical notions,
> 2) learns to understand the nature of mathematics as a theoretical discipline which is closely related to practice,
> 3) learns to apply mathematics
> 4) learns to perform deductions and inferences
> 5) learns to understand and produce material containing mathematical symbols and terminology.

The affective objectives are considered in this investigation in the formulation of the 1970 curriculum (objectives 3) and 4) p. 5).

3. THE ELECTRONIC HAND CALCULATOR AND MATHEMATICS EDUCATION

3.1. General Remarks

The rapid increase in the number of electronic hand calculators available for pupils has often been regarded with concern by mathematics teachers. In order to prevent the development from getting of hand, the National Board of Schools issued a circular in 1976 prohibiting the use of electronic hand calculators in mathematics teaching in the comprehensive school for the time being. A revised approach to this question is, however, expected in the very near future. This revision is becoming urgent on account of several facts. The rapid increase in the sales of the electronic hand calculators due to the continuously sinking price level is transforming the hand calculator into a virtually universal computing device. Several authorities on mathematics education have expressed the opinion that the carefully planned use of the electronic hand calculator can open quite new vistas for mathematics education (e.g. Suydam 1976, Gawronski et al. 1976; NCTM 1977).

Even though it is possible that in the future the electronic hand calculator will be so common that practically everyone has one available, this does not imply that traditional computation will become obsolete. The necessity of a certain level of mental computation is obvious. The importance of estimation skills may even increase with the advent of the calculator. It will be necessary to be able to estimate whether the result obtained is reasonable, especially considering how easy it is to make mistakes when entering numbers into the calculator.

It also seems highly probable that skill in algorithmic computation is an important prerequisite for the development of mathematical thinking (see Usinski & Bell 1976). The importance of algorithmic computation in developing accuracy should not be underestimated. It is also important for a person to have confidence in oneself and to know that he is able to cope with common computational tasks without mechanical aids, the necessity for which may arise in unexpected situations in which no calculator is available.

We can thus proceed on the assumption that traditional-type arithmetic and computation will in the near future occupy a sizable portion of the mathematics curriculum in the elementary school.

3.2. The Electronic Hand Calculator and Mathematics Curricula

Weaver (1976) has classified three kinds of mathematics curricula in respect to their dependence on calculators:

- CA- (Calculator-Assisted) curricula, in which the calculator is used to supplement a curriculum drawn up regardless of it,
- CM- (Calculator-Modulated) curricula, in which curricular content has been modulated to conform to calculator characteristics, and
- CB- (Calculator-Based) curricula, in which instruction is based and dependent on the calculator.

This characterization is hierarchic in that CB-curricula can be thought of as constituting a subset of CM-curricula which in turn constitute a subset of CA-curricula.

The aims of this investigation are quite practical and short-term. Thus a CA-type approach was adopted so that the potential advantages of the calculator could be util-

ized in the present type comprehensive school curriculum. We adopted this approach in spite of the fact that we agree with Usinski and Bell (1976) in that this approach poses several risks. The greatest danger seems to be that the introduction of the calculator into a curriculum, which has been drawn up without taking it into consideration, may weaken such skills as are indepensable to the functioning of the curriculum. It should, however, be possible to prevent the materialization of these risks by carefully planning the context in which the calculator is used and the manner of its utilization.

3.3. Uses of the Electronic Hand Calculator at Different Levels of the Comprehensive School

At this moment use of the calculator in mathematics education is permitted only in the upper secondary school (grades 10 - 12). We next consider some potential uses of the calculator in the comprehensive school.

3.3.1. The Elementary School (grades 1 - 6)

The following remarks are to a certain extent based on the investigation by Immerzeel et al. (1976).

In grades 1 - 3 it would seem that only occasional and very well supervised use of the electronic hand calculator can be advocated. At this level children learn the basic facts of natural numbers and their manipulation. Thus the risks inherent in permitting free use of the calculator are evident. In principle it is, of course, quite possible to utilize the calculator already at this stage - and even at the pre-school level - to help pupils discover connexions between numbers, but such activities have to be very carefully planned indeed. Such activities could, for example, include dis-

covering the connexion between addition and multiplication, developing decimal notation or constructing tables.

When the basic facts have been learned in grades 1 - 3 there is a variety of ways in which the calculator can be used in grades 4 - 6.

1) Securing the number concept and positional notation when dealing with large numbers and decimals.
2) Mental and written computation and estimates can be checked individually by means of the calculator.
3) Calculators can be used to discover laws and rules of computation, for example the behaviour of the decimal point in multiplication and division by the powers of ten or "checking" the associative law with large numbers.
4) Conversion of fractions to decimals and vice versa.
5) Performing area and volume calculations with realistic data.
6) Practical problems and interesting real life situations which formerly involved forbidding calculations become manageable in school. Especially calculations involving percentages become easier to handle.
7) The calculator can have effects on raising motivation.
8) The calculator can be used for project work and with laborative material.

It would seem a priori that the potential didactical advantages of the calculator would be greatest at this level.

3.3.2. The Lower Secondary School (grades 7 - 9)

As noted above, at the elementary school level the calculator has considerable potential possibilities as a reinforcer of learning and as an aid to concept forma-

tion and inductive teaching strategies. At the lower secondary level the calculator would appear to be primarily a convenient computational device replacing the slide rule. Also at this level, however, there are topics in which the calculator can be used as an aid to concept formation:

1) Basing the function concept on a machine model and using the calculator to compute values of functions has proved to be a fruitful approach to the function concept.
2) The introduction of irrational numbers e.g. as solutions of equations of the type $x^2 = 3$ can easily be performed by computing upper and lower estimates. Thus the convergence of rationals toward the root is illustrated concretely.
3) Values of difference quotients can be calculated and thus the derivative is approached.

As a computational aid the calculator can be used in the following contexts:

1) Roots of equations are easily checked even when they are not simple integers.
2) Applications can be dealt with more widely than before when complicated computations need no longer be avoided. Thus the emphasis can be placed on finding an appropriate method of solution. Complicated problems involving percentages or compound interest become much easier to handle.
3) Topics dealing with probability and statistics can be handled freely.
4) Calculations involving everyday consumer math such as computing unit prices, discounts etc. become more feasible.
5) Applications of trigonometry become easier when computational difficulties and use of tables are eliminated.

The availability of the calculator in mathematics classes would also encourage its use in subjects applying mathematics such as physics, chemistry, home economics, geography, technical shop, etc.

3.3.3. The Calculator and the Underachieving Pupil

The possibilities of the electronic hand calculator may be especially interesting in the case of pupils who perform poorly in methematics. It would seem that having a tool at one's disposal to check one's work would serve to increase self-assurance. Using the calculator, such pupils can more easily handle concrete and familiar mathematical situations, which should increase motivation. In the case of pupils for whom some mechanical computations such as long division remain an insurmountable hindrance, it might be possible to consider letting them use a calculator to perform the "impossible" computations, so they can pass on to other topics together with the rest of the class. This kind of a procedure involves the risk, however, that the teacher will too easily give up in the case of pupils who do not learn as quickly as most.

Sporadic evidence from teacher who have experimented with the calculator also indicates that it possesses considerable possibilities in raising the level of motivation of underachieving pupils.

3.4. The Calculator and the Aims of Mathematics Education

Above we have investigated some possible uses of the calculator in mathematics teaching. Such use must of course be compatible with the overall aims of education as well as the specific aims of mathematics education. As the electronic hand calculator is becoming

a more and more common tool in different fields and in everyday life, it would seem that learning how to use it and how to draw maximum profit from it would be compatible with the aims of the comprehensive school enumerated in 2.3. (p. 5). We next investigate the use of the calculator in respect to the cognitive aims of mathematics teaching formulated on p. 6. Afterwards we shall consider the affective aims.

3.4.1. Cognitive Aims

Computation and use of basic facts

Perhaps the greatest doubts have been raised regarding the possible negative effects of the electronic hand calculator on the ability and willingness to perform computations. It could be thought that when pupils get the answer by merely pushing buttons, it would be difficult to motivate them to practice mental and written computation to a sufficient extent. Such dangers can, however, be taken into consideration and prevented by means of sufficient planning. If use of the calculator in a greater measure is delayed until after grade 3 at the earliest, the basic facts of addition, subtraction, multiplication, and division should have been learned to the level of automatization. Use of the calculator in checking results gives rapid feedback which could increase motivation. By means of games and competitions in which pupils using calculators compete with those who don't, pupils can be made to realize the necessity and desirability of computational skills. The calculator can also be used to give deeper insight into the nature of mathematical laws and algorithms.

Understanding mathematics

It could be argued that the introduction of the calculator will decrease the necessity of understanding mathematics when computation is reduced to mere button

pushing. Such a view implies that mathematics is understood in a very narrow sense as being merely mechanical- or even numerical computation. Nearly every mathematical task except outright mechanical drill, however, involves an analysis of the situation and a decisicn of at least what computations to perform and the order of their performance. The numerical computation is often the last stage of the solution and it is preceded by most mathematically interesting and important steps.

Understanding mathematical principles at the pupil's level of development is an important and demanding aim of mathematics teaching, which has been strongly emphasized by the recent reforms of mathematics education in different countries. Using the calculator in teaching concepts and principles in an inductive manner can contribute towards attaining this aim. It is, for example, possible to base concepts such as the function or proportionality on extensive numerical data more easily than before the calculator was available.

Applying mathematics

It is obvious that having a calculator available makes it easier to handle real life situations mathematically. The emphasis can be laid on finding the appropriate strategies for solution and constructing suitable mathematical models when computional difficulties recede. Also the integration of mathematics with other subjects gains new possibilities.

Deduction

The availability of greater amounts of numerical data will probably involve the use of inductive teaching strategies more frequently than before. Consequently the necessity to perform binding proofs will increase, due to the desire to validate results in a general fashion. One can also "check" results of deductions

e.g. by using large or small numbers. Finding counter-examples becomes easier to perform, too, and thus the nature and necessity of deductive techniques is illustrated.

Mastering symbolic language

This field would a priori appear to be least of all dependent on the use of the calculator. Successful use of the calculator, however, involves the correct formulation of expressions and e.g. appropriate use of brackets. Programmable calculators and computers are evidently closely related to this objective.

3.4.2. Affective Aims

Using the calculator may increase the self-confidence of the pupil as he realizes that he is able to handle a technical appliance and can solve demanding tasks with it. This could apply especially to underachieving pupils. On the other hand heavy reliance on the calculator may result in an undesirable dependence on a technical device.

In respect to the affective aims of the comprehensive school formulated in 2.3. (objectives 3) and 4)), the calculator may bring new motivation and eagerness to the study of mathematics by increasing the amount of interesting applications which it is possible to cope with in school. Thus the objective of having pupils experience pleasure is attained, and this can happen more easily than before in the case of underachieving pupils.

One learns quite rapidly that the efficient use of the calculator demands considerable mathematical knowledge. As molding the data available into computable form often demands much work, one gets an idea of the limits of computation and mathematics in general in problem

solving. Thus the use of the calculator can serve to help the pupils to adopt a realistic attitude to the possibilities and restrictions of mathematics.

Above we have investigated the use of the calculator in respect to the aims of mathematics education. The analysis has shown that deliberate use of the electronic hand calculator can potentially contribute towards attaining these aims. If and when the calculator is introduced into mathematics teaching in the comprehensive school, care must be taken to assure that a sufficient level of the abilities to perform mental and written computations is upheld. Thus the calculator will serve to make the task of defining the desirable level of mathematical literacy and especially of computing skills even more urgent than it has been before (Magne 1975, Usinski and Bell 1976, Hamrick and McKillip 1978).

3.5. A Review of Research Involving the Calculator

There has been a substantive amount of research involving the electronic hand calculator in mathematics education going on especially in the United States since the early seventies. However, a large portion of the research is qualified by Suydam in her review (1976) as action research, inquiry, preliminary research, the results of which cannot be considered to be more than tentative. In table 3.5.1. there is a summary of pertinent research available to the author by late 1979. From the relatively large amount of research reviewed in the Bulletins of the Calculator Information Center and other sources, the ones referred to in the table have been chosen to fulfil the following criteria:

1) The research must be experimental
2) The research must deal with mathematics teaching in grades 1 - 9

3) The empirical research must be performed in regular school surroundings, not in summer camp for example.

In table 3.5.1. results are classified according to the same ability components as are used in the experimental part of this investigation. An x in the column denotes a significant difference in favour of the group using the calculator and a line that no significant difference was found. An empty space denotes the fact that the component was not tested. The figures in the third column indicating the grade level and the number of pupils participating include both experimental and control groups.

As is seen from table 3.5.1. there does not appear to be a very clear trend on how the use of the calculator is related to achievement and attitudes in mathematics education. One thing seems clear, however, in none of the research reviewed was there found any indication that calculator users have achieved significantly poorer results than the control group. Even accounting for a considerable Hawthorne effect, this observation seems to be so uniform as to merit attention.

In a considerable number of investigations, students using calculators have achieved significantly better than the control groups, primarily on tests of computation and understanding. Most significant results seem to have been achieved, however, in investigations with relatively small numbers of participating pupils. This could partly depend on the fact that such small scale experiments are easier to control than large ones. It should also be noted that most tests have been administered immediately following the experimental treatment. In those rare investigations where long-term effects have been considered, the possible differences seem to have disappeared.

Table 3.5.1. Review of selected investigations

Author	Year	Grade level/ no. of ss.	Duration	Manner of use of calculator	Differences of Posttest Results: Computation	Understanding	Estimation	Application/ Problem solving	Total	Attitude
Whitaker	1977	1.	30 d	checking	×			×	-	-
Grayson & al.	1979	2.-6./1500	14 wk	various	-		-		-	-
Eckmier	1978	4.-6.	9 mo	checking					-	-
Kobrin	1978	4.-6./216	1 yr	selected activities					-	
Wheatley	1979	5./50	3 mo					-		
Spencer	1975	5./40 6./44	8 wk	special materials	×	×			×	
Sutherlin	1977	5.-6./ 8 classes	8 wk	estimation			-			
Campbell & Virgin	1976	5.-6./ 2 schools	7 mo	aid	-	×		×		
Jones	1976	6./171	9 wk	1 hr/d	×	×			×	-
Anderson	1977	7./ 12 classes	20 wk	applic., checking	-	-			-	×
Jamski	1977	7./ 6 classes	4 wk	percent., conversion	×					
Rudnick	1976	7./700	1 yr		-					-
Williams	1978	jr. high 9 classes	1 yr	general mathematics	-					×
Hutton	1976	9./ 3 groups	4 wk	powers roots radicals					-	-
Kolpas	1978	9./80	20 wk		-				×	
Wajeeh	1976	9./ 13 classes	15 wk		×					-
Vaughn	1977	9./ 8 classes	8 wk	special curriculum					×	

3.6. Conclusions on the Use of the Calculator

In spite of the often voiced reservations as to the use of the electronic hand calculator in the comprehensive school and particularly at the elementary level, the analysis undertaken above and the empirical research referred to, seem to indicate that the calculator can contribute considerably towards attaining the aims of mathematics education. Optimal utilization of the calculator would seem to involve a considerable change in the attitude of teachers as well as considerable resources allocated to development of CM- and CB-curricula (see p. 9). Before radical innovations are undertaken, the consequences of widespread use of the calculator have to be investigated both theoretically and empirically.

Much of the research referred to deals with the use of the calculator in a CA-type curriculum drawn up without consideration of the calculator. Even in this setting results of well supervised calculator use seem to be promising.

We next proceed to report the results of a small scale empirical investigation dealing with use of the calculator at the elementary level of the Finnish comprehensive school.

4. HYPOTHESES

The discussion of chapter 3 gives rise to several hypotheses on the relation between using electronic hand calculators on one hand and mathematical achievement and attitudes towards mathematics on the other. It appears to be useful to define certain components of mathematical ability that can be presumed to be related with the use of the calculator:

- the ability to perform mechanical and numerical computations
- the ability to understand mathematical principles and apply them
- the ability to perform estimations
- the ability to apply mathematics.

These components of mathematical ability are not directly connected with the N, V, R, D, etc. factors derived from factor analytic research of the mathematical ability (Werdelin 1958, Treumann 1974, Leino 1977a) nor with components arising from considerations involving the so-called logical structure of ability (Krutetskii 1976). For this investigation a more concrete a priori classification of the components of mathematical ability has been adopted. These particular components have been chosen because they embody those aspects of mathematical ability which would seem to be most liable to being affected by the use of the calculator.

Although the empirical part of this investigation is not strictly experimental, it seemed useful to pose hypotheses to be tested. The discussion of chapter 3 implies that we can assume the effect of the calculator on the different components of mathematical ability to be non-negative. We set the following hy-

potheses:

1) Pupils who have used calculators perform better on computation tasks than those who have not used them.
2) Pupils who have used calculators are able to understand and apply mathematical principles better than those who have not used them.
3) Pupils who have used calculators perform better on estimation tasks than those who have not used them.
4) Pupils who have used calculators can apply mathematics better than those who have not used them.
5) The attitude of pupils who have used calculators is more positive towards mathematics than that of pupils who have not used them.

The discussion of chapter 3 allows us to assume the existence of an ATI- (Aptitude-Treatment Interaction) effect: pupils who perform poorly in mathematics may profit more from using the calculator than others. Consequently we shall investigate auxiliary hypotheses stating an interaction between mathematical ability and use of the calculator in respect to the ability components and the attitude factor of hypotheses 1) - 5).

The level for rejecting the null hypothesis is chosen as $p < .05$.

5. THE EMPIRICAL INVESTIGATION

The empirical part of this investigation could be classified as preliminary classroom research (Gage 1963). The experimental design is the non-equivalent control group design and thus belongs to the domain of pseudo-experimental research (Campbell & Stanley 1963). As so often in classroom research, it was not possible to assign pupils to experimental and control groups at random.

5.1. The Variables

The independent variable is the use of the electronic hand calculator in mathematics teaching. The dependent variables are the components of mathematical ability defined in chapter 4: the ability to perform mechanical computations, the ability to understand and apply mathematical principles, the ability to perform estimations and the ability to apply mathematics as well as the attitude towards mathematics.

To test the ATI-effect the report card mark in mathematics was selected as a distributive variable. In Finland the pupils are marked at the end of the autumn and spring terms on a scale ranging from 4 to 10 with 4 denoting failing and 10 excellent marks. Although this variable is sure to correlate with the different components of mathematical ability selected as dependent variables, this choice was regarded as the only one possible for classifying the pupils according to different levels of mathematical ability. The report card mark is generally considered a natural general measure of scholastic achievement even though it is undoubtedly dependent on many attitude factors

and uncontrollable factors in addition to actual ability factors (Leino 1977b).

5.2. The Subjects

In Finland, pupils learn the basic addition, subtraction, multiplication and division facts in grades 1 - 3. In grade 4 the long division algorithm is taught and negative integers are introduced. The pupils also begin their study of how to perform calculations with common and decimal fractions. The curriculum emphasizes the application of arithmetic skills to problem solving.

The experimental subjects of this investigation were the pupils of the fourth grades of the Kyläneva elementary school, which is a part of the Department of Teacher Education of the University of Helsinki. In this school occupied with teacher training the influence of the teacher is to a certain degree randomized: the great majority of classes is taught by teacher trainees who change every five weeks.

As a control, the pretest and posttest were also administered in two fourth classes, labelled D and E, of the Yliskylä elementary school which is not involved in teacher training but is comparable to the Kyläneva school in other respects.

The results of the pretest showed that there were no significant differences between the three classes labelled A, B, C, of the Kyläneva school (table 5.2.1. in Appendix 1 and table 5.6.2.2. in Appendix 4). Classes B and C were chosen as the experimental group and class A as the control group. The number of students in the different classes is given in table 5.2.2.

Class	Pupils in grade 4	Pupils having taken pretest in grade 3		
A	21	21	Control	Kyläneva school
B	20	18	Experim.	
C	20	14	-"-	
D	30	24	Control	Yliskylä school
E	32	28	-"-	
Total	123	105		

Table 5.2.2. Number of Pupils in Experimental and Control Groups

5.3. The Tests

Two test batteries, a pretest administered in May 1977 at the end of grade 3 and a posttest administered in May 1978 were drawn up to measure the selected components of mathematical ability. The tests are to be found appended to the original Finnish-language version of this report (Paasonen 1979).

The tests of numerical computation consisted of three speed tests for mental addition, subtraction, multiplication and division and of a test of algorithmic computation.

The tests for understanding consisted of two parts. The first part measured understanding of the positional system, comparing numbers as to size, and relations between addition and multiplication, addition and subtraction, etc. The second part was a true-false test measuring understanding of the laws of arithmetic: one must for example decide whether the statement $348 \cdot 971 = 971 \cdot 348$ is true or not.

In the estimation tests, pupils had to solve problems of type: "Estimate which four out of five given priced

items can be purchased for 50 marks". The idea of this kind of test was gotten from an investigation by Holmberg (1974).

The test for application consisted of relatively standard word problems of the type encountered in the textbooks used by the pupils.

The attitude test was a Likert-type test adapted by Karjalainen (1976) from a test by Dutton and Blum (1968) and tried out by him in an investigation of mathematics teaching in Nothern Finland (Karjalainen 1976). The suitability of using a Likert-type test at this level had been ascertained by Holmberg (1974).

5.4. Calculator Usage during the Experimental Stage

The experimentation began at the end of September 1977. Each pupil was given a calculator by the classroom teacher and one lesson was devoted to instruction in its use. The calculators were Commodore LC-81 liquid chrystal display calculators featuring addition, subtraction, multiplication, and division keys as well as percentage, square root and change of sign keys.

According to the teachers' observations, all pupils learned to handle the calculators and were quite enthusiastic about them. When not in use, the calculators were kept in a cupboard in the classroom and distributed on the occasions when the teacher thought that they should be used. The parents of the children were instructed not to let their children use calculators possibly available at home for doing or checking mathematics problems. About 75 % of the 123 pupils in the experiment had calculators at home.

Calculators were mainly used in classes taught by teacher trainees. While the experiment lasted, there were six

to seven different student teachers teaching mathematics in each of the three classes. The students teaching in the experimental classes were given written and oral instructions about some ways in which the calculator could be used before their teaching period started and while it lasted. The attitudes of the student teachers ranged from enthusiasm to scepticism and annoyance about the surplus work planning the use of the calculator would perhaps bring with it.

Pupils attitudes towards the calculator

Soon after the Christmas holidays when the calculator had been used for somewhat less than 3 months, the experimental group was given a test to measure skill in using the calculator and attitudes towards it. The test results (table 5.4.1. in Appendix 2) indicate that use of the calculator was almost universally considered pleasant and easy. Few mistakes were made in computation, and basic applications were mastered satisfactorily. No change towards the negative was observed in these factors as the year went on.

How the calculator was used

After each lesson during which the calculator had been used the teacher filled in a form specifying the time and manner of usage. Relatively little use was made of the calculator: in class B it was used during 18 lessons and in class C during 23 lessons, which corresponds to 24 % and 31 % of the total 75 lessons held from the end of September to the beginning of May. The ways in which the calculator was used and their frequencies are given in table 5.4.2.

The calculator was most frequently used for checking computations and next for introducing new topics in an inductive manner. It also appeared to be suitable for

Manner of use	Class B		Class C		Total	
	f	%	f	%	f	%
Introducing new topic	4	21	7	22	11	23
Solving word problems	1	5	2	9	3	6
Checking schoolwork	9	48	12	40	21	43
Checking homework	0	0	1	3	1	2
Estimation	1	5	1	3	2	4
Mental computation	4	21	4	13	8	16
Other	0	0	3	10	3	6
Total	19	100	30	100	49	100

Table 5.4.2. Uses of the Calculator

arranging practice in mental computation. We can thus conclude that these modes of use are relatively well suited even when working with standard textbooks and curricula.

We note from table 5.4.2. that in addition to the fact that the calculator was used in class C during 23 lessons as opposed to 18 in class B, the manners of usage were also more varied in class C. This may depend on the fact that, even though assignment of student teachers to the different classes is quite arbitrary, several enthusiastic student teachers happened to be assigned to class B.

The calculator was mostly used for brief 6 - 10 minute stretches at the beginning or end of the lesson. It was almost always used by all pupils. Thus the calculator did not seem to be easily adaptable to differentiation in the classroom. Calculators were also used at a few remedial instruction sessions.

The teachers judged without exception that use of the calculator had been useful and that the pupils had been interested in using it.

5.5. Statistical Methods for Analyzing the Results

t-tests were used to test the differences of means between the experimental and control groups following one-way analysis of variance over the different classes.

Since some differences on the pretest were evident between classes A, B, and C (see table 5.6.2.2. in Appendix 4), an analysis of covariance of the post-test scores with the pretest scores as covariates was performed to determine the extent of the effect of pretest differences on the results.

To test the ATI-effect between mathematical ability and benefitting from use of the calculator, a two-way analysis of variance was performed with the students grouped into four ability groups according to the 1977 spring report card mark in mathematics. As the cell frequencies were small for the extreme groups, no significance tests on the part of the individual groups were performed. Instead, differences of pretest-post-test score averages are reported in the ability groups. As pointed out by Cronbach and Snow (1977), conclusive ATI-experiments should have at least 100 subjects per treatment to make the probability of not succumbing to beta-type error reasonable. This will be kept in mind when interpreting the results.

The two-way analyses of variance and the analyses of covariance are reported for the three Kyläneva school classes only, as teaching at the Yliskylä school was not subject to any kind of control on the part of the investigator.

5.6. Results and Their Interpretation

5.6.1. Reliability and Validity

The reliability coefficients (Cronbach alpha) for the pretests and the posttests on attitude, understanding and application are given in table 5.6.1.1.

Test	Pretest	Posttest
Attitude	.84	.86
Understanding	.77	.69
Application	.71	.80

Table 5.6.1.1. Reliability coefficients for selected tests

Since the tests of mechanical computation and estimation were speed tests, standard reliability coefficients measuring internal consistency are not applicable. The reliability of these tests was estimated by means of the pretest-posttest correlation of the Yliskylä school pupils, who were not subject to experimental treatment. The coefficients of correlation were $r = .75$ for the computation test and $r = .21$ for the estimation test. Thus all other tests except the estimation test can be considered satisfactorily reliable. It should be noted that in constructing the tests, maximum reliability was not striven for, as several very easy items were posted at the beginning of each test to give the weaker pupils a motivation to try them.

A measure of validity is offered by the correlation of the tests with an independent measure of mathematical ability such as the report card mark. These correlations are given in table 5.6.1.2.

Test	r
Mechanical computation	.80
Understanding	.64
Estimation	.33
Application	.76
Attitude	.21

Table 5.6.1.2. Correlations of posttest scores with report card marks in mathematics (spring 1978)

The correlations are relatively high except for the estimation test and the attitude test. The low correlation of the attitude test with the report card mark may at first seem somewhat surprising. This type of relatively simple attitude measurement has widely been criticized for not yielding significant information, (e.g. NACOME 1975), and this criticism appears to receive support from results such as these. The fact that the subjects are quite young - age 11 - 12 - could also contribute to the fact that their attitude structure has not yet been stabilized (compare Malinen 1969, Leino 1977b and 1978).

5.6.2. Test Results and Their Interpretation

All classes

The one-way analyses of variance in table 5.6.2.1. (Appendix 3) indicate that the null hypothesis concerning differences between all five classes involved must be accepted on all pretests and posttests. Classwise means and standard deviations are reported in table 5.6.2.2. (Appendix 4).

A comparison of the pretest results of the Yliskylä school (classes D and E) and the Kyläneva school clas-

ses indicates that the Yliskylä pupils received somewhat higher scores on many tests. This is partly explained by the fact that in grade three they had studied according to the old primary school curriculum featuring four weekly mathematics lessons while the Kyläneva school had had only three according to the new comprehensive school curriculum. It is of interest that this trend has partly been reversed in the posttest in the case of the students having used the calculators (classes B and C).

Kyläneva school

The corresponding analyses of variance for the three Kyläneva school classes involved in the actual experimentation indicate that there is reason to reject the null hypotheses for the posttest scores on the computation, understanding, and attitude tests, while the analyses of variance of the pretest results do not yield significant differences (table 5.2.1. in Appendix 1).

Computing t-ratios for the differences of the averages of the Kyläneva school for those tests, whose analysis of variance reported in table 5.2.1. in Appendix 1 indicated the existence of significant differences, we note that the experimental class C scored significantly higher than class A (control) on the computation test, the understanding test and the attitude test. These significant differences are indicated by arrows in table 5.6.2.2. (Appendix 4). On the understanding pretest class C also scored considerably higher than both class A and B - the difference compared to class B, which also used the calculator has, however, become negligible on the posttest.

In general we note from table 5.6.2.2. that while the Kyläneva classes were, except for the understanding test, relatively equal on the pretest, on the posttest

class C (experimental) was almost consistently better than either of the other two classes and that the differences between class B (experimental) and the control group class A have increased. It might be recalled that the calculator was used in a more versatile manner in class C than in class B (page 29).

Hypothesis testing

To test the hypotheses in chapter four, the classes are grouped into experimental and control groups according to their using or not using the calculator. The information necessary for testing the hypotheses is gathered into table 5.6.2.3. (p. 34). The experimental group (classes B and C of the Kyläneva school) is compared with class A of the Kyläneva school on one hand and with the secondary control group consisting of class A and classes D and E of the Yliskylä school on the other. The corresponding pretest data are given in table 5.6.2.4. in Appendix 5.

The results collected into table 5.6.2.3. indicate that we can reject the null hypotheses concerning the effect of using the calculator on the ability to perform mechanical computations, the ability to understand and apply mathematical principles, the ability to apply mathematics and the attitude towards mathematics. We must, however, accept the null hypothesis concerning an effect of using the calculator on the ability to perform estimations, which may partly be due to a somewhat unsuccessful test.

Analysis of covariance

The analyses of covariance to determine whether the main effect - calculator usage - would be significant after the effect of pretest differences has been eliminated are reported in table 5.6.2.5. in Appendix 6.

	Exp	C_1	C_2	t_1	t_2
Mech. comp.					
$\bar{x}$	26.2	23.2	25.8	1.92*	.29
s	5.3	6.2	7.0		
max			38		
Understand.					
$\bar{x}$	24.4	22.1	23.0	2.30*	1.86*
s	3.3	3.7	3.5		
max			31		
Estimation					
$\bar{x}$	3.3	3.4	3.2	-.44	.47
s	1.0	1.1	1.4		
max			5		
Application					
$\bar{x}$	7.8	5.9	6.2	2.40*	2.63**
s	2.5	3.4	3.3		
max			12		
Attitude					
$\bar{x}$	61.5	54.2	56.3	2.73**	2.57**
s	8.3	11.1	10.1		
max			85		
n	32	21	73		

Explanations of symbols:

Exp	Experimental group (classes B and C)
C_1	Primary control group (Class A, Kyläneva school)
C_2	Secondary control group (Classes A, D, E)
t_i	t-ratios for differences of averages between groups Exp and C_i ($i = 1,2$)

Table 5.6.2.3. Means, Standard Deviations and t-ratios for Posttest Results

The results indicate that including the corresponding pretest scores as covariates into the covariance model does not decrease the significance of the calculator variable.

Testing for the ATI-effect

The two-way analyses of variance with mathematical ability as measured by the report card mark and the use of the calculator as classifiers is reported in table 5.6.2.6. in appendix 7. No significant interactions were evident, so the hypotheses ventured at the end of chapter four on the interaction of mathematical ability and profiting from calculator usage must be rejected. It must be pointed out, however, that the risk of committing a beta-type error is very large with such a small sample (Cronbach and Snow 1977).

Comparing the differences of the averages of the experimental and control groups on the pretests and posttests (table 5.6.2.7. on page 36) at the different ability levels, a striking improvement on the part of the lowest ability group (marks 4 - 6) is evident on all tests except the estimation test. As no similar equally marked trend is noticeable at the other ability levels, this would indicate the possible existence of the expected ATI-effect in spite of the non-significant ANOVA results.

		Pretest				Posttest			
		4-6	7	8	9-10	4-6	7	8	9-10
Mech.comp.									
Exp	$\bar{x}$	16.0	32.0	30.8	36.8	18.7	24.4	26.8	32.2
	s	2.0	5.7	5.5	3.3	3.2	3.9	4.5	4.1
C_1	$\bar{x}$	17.3	28.4	31.3	40.3	16.7	20.1	24.3	34.0
	s	3.1	4.6	3.8	1.5	1.5	2.7	4.4	3.5
	d	-1.3	3.6	-.5	-3.5	2.0	4.3	2.5	-1.8
Understand.									
Exp	$\bar{x}$	16.3	17.0	20.0	22.0	20.0	21.9	25.8	26.0
	s	2.5	2.2	3.5	2.7	3.6	3.7	2.1	1.9
C_1	$\bar{x}$	15.7	16.3	18.8	23.0	16.3	21.1	23.8	26.0
	s	3.1	2.4	2.8	2.6	2.1	2.4	2.8	1.9
	d	.6	.7	1.2	-1.0	3.7	.8	2.0	.0
Estimation									
Exp	$\bar{x}$	2.7	2.0	2.5	2.2	3.0	3.0	3.4	4.0
	s	.6	1.0	.9	1.3	1.0	.6	.9	1.2
C_1	$\bar{x}$	2.3	2.1	2.6	3.0	4.0	2.7	3.6	4.0
	s	.6	1.1	.7	0.0	1.0	1.3	.9	1.0
	d	.4	-.1	-.1	-.8	-1.0	.3	-.2	.0
Application									
Exp	$\bar{x}$	2.0	5.4	5.9	10.2	3.3	6.7	8.3	10.6
	s	1.7	1.7	1.7	2.4	.6	2.2	1.8	1.7
C_1	$\bar{x}$	4.0	4.7	6.6	9.3	2.0	4.0	7.3	10.7
	s	1.7	2.2	2.2	1.5	1.7	2.9	1.6	.6
	d	-2.0	.7	-.7	.9	1.3	2.7	1.0	-.1
Attitude									
Exp	$\bar{x}$	66.0	58.6	64.3	71.6	64.3	57.6	61.8	64.6
	s	15.1	11.7	9.5	5.0	5.5	8.9	8.8	7.2
C_1	$\bar{x}$	62.3	68.3	63.8	70.0	50.7	53.3	52.2	64.7
	s	4.5	6.5	11.8	9.2	16.5	11.0	9.5	8.1
	d	3.7	-9.7	.5	1.6	13.6	4.3	9.6	-.1
Exp	n	3	7	17	5	3	7	17	5
C_1	n	3	7	8	3	3	7	8	3

Table 5.6.2.7. Means and Standard Deviations of Pretest and Posttest Results Classified According to Mathematical Ability as Measured by the Report Card Mark

6. DISCUSSION

The hypotheses claiming that calculator use in mathematics teaching could have a positive influence on the ability of comprehensive school pupils to perform mathematical computations, to understand and apply mathematical principles, and to apply mathematics as well as on their attitude toward mathematics were supported by the results of the empirical parts of this investigation (table 5.6.2.3. on page 34).

A slight though statistically non-significant ATI-effect was observed between mathematical ability and calculator use. Especially the lowest ability group seemed to profit considerably more than others from the use of the calculator.

The experimentation took place in a teacher training school. This was advantageous in that the teacher variable was to a certain degree randomized by the changing every five weeks of the teacher instructing the class. Also, the pupils are accustomed to different and varying instructional techniques, which could imply that the introduction of a new device such as the calculator may not have been as great an occasion as for normal school pupils. The initial differences of the classes involved were mostly quite slight and their effect on posttest results was controlled by means of an analysis of covariance. An attempt was made to structure the instruction in the three classes involved in as similar a manner as possible.

The theoretical and experimental results of this investigation together with results of research abroad seem to indicate that the electronic hand calculator can effectively be used to pursue the aims of mathematics education in the comprehensive school. Measures must, how-

ever, be taken to guarantee a necessary level of written and mental computation also after the eventual introduction of the calculator.

The small number of pupils and the special character of the teacher training school, in which the experimentation took place, warrant caution in generalizing the experimental results. The experiment also indicated clearly that use of the calculator in connexion with a curriculum and textbook materials produced without considering its utilization is not unproblematic. This was evidenced by the relatively restricted use made of the calculator and the ways in which it was used (see 5.4.).

It seems probable that more use of the calculator could be made in grades 5 and 6. The Finnish curriculum in these grades provides for more applications and more operations with fractions, decimal numbers and integers than in grade four. More conclusive evidence on the positive effects of the calculator would demand a more comprehensive experimental project with a greater number of schools and different grade levels involved. Simultaneously, work should be instigated to develop and test CB- and CM-type curricula applicable to Finland and to investigate theoretically and empirically the effects of their introduction on mathematics education and the demands the introduction of the calculator would set to teacher training.

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	Pretest				Posttest			
Mechanical comp.								
Source of variance	ss	df	ms	F	ss	df	ms	F
Between classes	105	2	52.5	1.03	213	2	106.6	3.44*
Residual	2554	50	51.1		1547	50	30.9	
Total	2659	52			1760	52		
Understanding								
Source of variance	ss	df	ms	F	ss	df	ms	F
Between classes	69	2	34.6	3.04	87	2	43.7	3.66*
Residual	568	50	11.4		598	50	12.0	
Total	637	52			685	52		
Estimation								
Source of variance	ss	df	ms	F	ss	df	ms	F
Between classes	1.5	2	.76	.92	3.5	2	1.8	1.79
Residual	41.2	50	.82		48.9	50	1.0	
Total	42.7	52			52.4	52		
Application								
Source of variance	ss	df	ms	F	ss	df	ms	F
Between classes	2	2	1.0	.14	48	2	24.0	2.76
Residual	362	50	7.2		436	50	8.7	
Total	364	52			484	52		
Attitude								
Source of variance	ss	df	ms	F	ss	df	ms	F
Between classes	270	2	134.8	1.43	694	2	347	3.77*
Residual	4707	50	94.1		4606	50	92	
Total	4977	52			5300	52		

Table 5.2.1. One-Way Analyses of Variance for Pretest and Posttest Results in Kyläneva School (Classes A, B, C)

Item	$\bar{x}$	s
How much fun is using the calculator? (1 = much fun, 3 = no fun)	1.0	0.0
How easy is using the calculator? (1 = easy, 3 = difficult)	1.1	.2
Skill in mechanical manipulation (max = 9)	8.2	1.0
Skill in simple applications (max = 5)	3.9	.9

Table 5.4.1. Calculator use test means and standard deviations

	Pretest				Posttest			
Mechanical comp.								
Source of variance	ss	df	ms	F	ss	df	ms	F
Between classes	151	4	37.8	.81	345	4	86.2	2.16
Residual	4646	100	46.5		3991	100	39.9	
Total	4796	104			4336	104		
Understanding								
Source of variance	ss	df	ms	F	ss	df	ms	F
Between classes	89	4	22.3	1.88	112	4	28.1	2.45
Residual	1186	100	11.9		1146	100	11.5	
Total	1275	104			1258	104		
Estimation								
Source of variance	ss	df	ms	F	ss	df	ms	F
Between classes	3	4	.7	.85	6	4	1.5	.94
Residual	81	100	.8		157	100	1.6	
Total	84	104			163	104		
Application								
Source of variance	ss	df	ms	F	ss	df	ms	F
Between classes	44	4	11.0	1.39	65	4	16.3	1.68
Residual	786	100	7.9		970	100	9.7	
Total	830	104			1035	104		
Attitude								
Source of variance	ss	df	ms	F	ss	df	ms	F
Between classes	491	4	122.6	1.47	781	4	195.2	2.09
Residual	8349	100	83.5		9321	100	93.2	
Total	8840	104			10102	104		

Table 5.6.2.1. One-Way Analyses of Variance for Pretest and Posttest Results (All Classes)

	Pretest					Posttest				
Class	A	B	C	D	E	A	B	C	D	E
Mech.comp.										
$\bar{x}$	29.6	32.1	28.7	31.7	31.4	23.2	24.9	28.2	28.0	26.0
s	7.3	6.6	7.6	6.8	6.1	6.2	5.0	5.3	6.9	7.0
Understand.										
$\bar{x}$	18.1	18.3	20.8	19.8	18.7	22.1	23.7	25.4	24.1	22.8
s	3.5	3.5	3.0	3.7	3.3	3.7	3.7	2.6	3.5	3.1
Estimation										
$\bar{x}$	2.5	2.2	2.6	2.7	2.4	3.4	3.1	3.7	3.1	3.1
s	.8	1.2	.6	.8	1.0	1.1	.9	.9	1.3	1.6
Applicat.										
$\bar{x}$	6.0	6.3	5.9	7.7	6.6	5.9	7.9	7.7	6.2	6.3
s	2.6	2.7	2.6	2.9	2.9	3.4	2.2	3.0	3.6	3.0
Attitude										
$\bar{x}$	66.0	62.0	67.4	68.0	64.1	54.2	62.2	60.6	58.0	56.5
s	9.0	12.3	6.5	8.2	8.8	11.1	9.3	7.2	8.7	10.5
n	21	18	14	24	28	21	18	14	24	28

Table 5.6.2.2. Classwise Means and Standard Deviations of Pretest and Posttest Results (Significant differences indicated by arrows in those cases in which ANOVA results implied rejection of null hypothesis)

	Exp	C_1	C_2	t_1	t_2
Mech. comp.					
$\bar{x}$	30.6	29.6	30.9	.52	-.23
s	7.1	7.3	7.0		
max		47			
Understand					
$\bar{x}$	19.4	18.1	18.9	1.34	.69
s	3.5	3.5	3.5		
max		26			
Estimation					
$\bar{x}$	2.3	2.5	2.5	-.52	-.93
s	1.0	.8	.9		
max		3			
Application					
$\bar{x}$	6.1	6.0	6.8	.17	-1.07
s	2.7	2.6	2.9		
max		12			
Attitude					
$\bar{x}$	64.3	66.0	65.9	-.58	-.80
s	10.4	9.0	8.7		
max		85			
n	32	21	73		

Explanations of symbols:

Exp	Experimental group (Classes B and C)
C_1	Primary control group (Class A)
C_2	Secondary control group (Classes A, D, E)
t_i	t-ratios for differences of averages between groups Exp and C_i $(i = 1,2)$

Table 5.6.2.4. Means, Standard Deviations, and t-ratios for Pretest Results

	Proportion of total variance (MCS)	ss	df	ms[x)]	F[x)]
Mechanical comp.					
Source of variance					
Main effect and covariate	.53	940	2	469.8	28.62^{xxx}
Residual	.47	821	50	16.4	
Total	1.00	1761	52		
Covariate	.46	814	1		
Main effect	.05	83	1		5.07^{x}
Understanding					
Source of variance					
Main effect and covariate	.42	288	2	143.9	18.1^{xxx}
Residual	.58	397	50	7.9	
Total	1.00	685	52		
Covariate	.33	223	1		
Main effect	.04	26	1		3.35^{x}
Estimation					
Source of variance					
Main effect and covariate	.09	4.7	2	2.3	2.4
Residual	.91	47.8	50	1.0	
Total	1.00	52.5	52		
Application					
Source of variance					
Main effect and covariate	.39	188	2	93.9	17.86^{xxx}
Residual	.61	296	50	5.9	
Total	1.00	484	52		
Covariate	.29	140	1		
Main effect	.10	44	1		7.41^{xx}
Attitude					
Source of variance					
Main effect and covariate	.37	1985	2	992.4	14.97^{xxx}
Residual	.63	3315	50	66.3	
Total	1.00	5300	52		
Covariate	.25	1310	1		
Main effect	.16	831	1		12.5^{xx}

Table 5.6.2.5. Analyses of Covariance for Posttest Results with Corresponding Pretest Scores as Covariates

x) The ms and F-values have been calculated from sums of squares with more decimals than indicated in table.

	Proportion of total variance (MCS)	ss	df	ms[x)]	F[x)]
Mechanical comp.					
Source of variance					
Main effects and interactions	.60	1055	7	150.8	9.62[xxx]
Residual	.40	705	45	15.7	
Total	1.00	1760	52		
Interaction	.03	46	3	15.2	.97
Ability grouping	.52	929	6	154.9	9.88[xxx]
Calculator usage	.06	111	4	27.7	1.77
Understanding					
Source of variance					
Main effects and interactions	.56	386	7	55.2	8.31[xxx]
Residual	.44	299	45	6.6	
Total	1.00	685	52		
Interaction	.02	15	3	5.0	.74
Ability grouping	.47	322	6	53.6	8.06[xxx]
Calculator usage	.06	44	4	11.0	1.66
Estimation					
Source of variance					
Main effects and interactions	.18	9	7	1.3	1.38
Residual	.82	43	45	1.0	
Total	1.00	52	52		
Application					
Source of variance					
Main effects and interactions	.65	313	7	44.7	11.8[xxx]
Residual	.35	171	45	3.8	
Total	1.00	484	52		
Interaction	.02	11	3	3.6	.94
Ability grouping	.55	265	6	44.2	11.63[xxx]
Calculator usage	.07	34	4	8.6	2.26
Attitude					
Source of variance					
Main effects and interactions	.24	1251	7	178.7	1.99
Residual	.76	4049	45	90.0	
Total	1.00	5300	52		

Table 5.6.2.6. Two-Way Analyses of Variance for Testing Interaction between Ability and Calculator Use

x) See footnote to Appendix 6.

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